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ENERGY PROGRAMS AT THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

JOHNS HOPKINS UNIVERSITY, LAUREL, MARYLAND

SEPTEMBER 1976

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Quarterly Report

ENERGY PROGRAMS

at The Johns Hopkins University Applied Physics Laboratory

SEPTEMBER 1976

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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This volume contains a record of the activities of the Applied Physics Laboratory in the field of energy research. Results are reported on work in the following categories: status of geothermal energy in the states of South Dakota, New Hampshire, Florida, and Arkansas; initial nonelectrical energy development and utilization scenario development at APL; maritime aspects of OTEC plant-ships; and a Community Annual Storage Energy System (CASES).

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SEPTEMBER 1976

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY
Johns Hopkins Road ∘ Laurel, Maryland ∘ 20810

Operating under Contract N00017-72-C-4401 with the Department of the Navy

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PREFACE

The Johns Hopkins University Applied Physics Laboratory is engaged under contracts with the U.S. Energy Research and Development Administration (ERDA) and with the U.S. Maritime Administration, Department of Commerce in the development of energy resources and energy-storage methods. This Quarterly Report summarizes, as appropriate, the work completed on the various tasks as of 30 September 1976.

The first section of this volume describes APL activities that assist the Planning Office of the Division of Geothermal Energy (DGE) of ERDA. Efforts in this field are concentrated on resource assessment and utilization in ERDA Region 5 (the continental United States east of the Rocky Mountain states, excluding Texas and Louisiana).

The second section consists of an article on APL's ocean thermal energy studies, sponsored by the Department of Commerce. The last section contains an article on a Community Annual Storage Energy System (CASES), sponsored by ERDA.

Future volumes will report the results of these and other energy-related projects in which APL is currently engaged.

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COMMENTS ON LIMITED TASKS

This section of the report discusses tasks that are either in the formative or terminal stage, or with which APL has assisted some other section of the Geothermal Division of ERDA.

MEETINGS AND TRIPS

Division of Geothermal Energy (DGE) Program Review, INEL

APL representatives (J. W. Follin, Jr., A. M. Stone, and F. C. Paddison) attended an ERDA review meeting of the Geothermal Program at Idaho International Engineering Laboratory (INEL) the last week in April 1976. While most of the ERDA geothermal program was familiar to APL from the progress reports of the various laboratories, the meeting was very helpful since it allowed us to meet the people involved in the various other programs and to be brought up to date on the status of the programs. APL presented a description of its plans to the geothermal community. On the third day of the meeting, a field trip was arranged by INEL to the drilling site in the Raft River Valley. The trip supplied first-hand information on the scope of drilling a large well and logging it properly for future documentation.

IECEC Conference

In the third week of September 1976, J. W. Follin, Jr., and R. J. Taylor attended the Intersociety Energy Conversion Engineering Conference (IECEC) meeting at Lake Tahoe. One of the six coincident sessions was on geothermal energy, to which 2½ days were allocated. In particular, the sessions on Stirling cycle and other heat pumps and engines were very constructive, as were some of the sessions on energy conservation and urban energy management.

Visit to USGS, Menlo Park

R. L. Eberhardt and T. W. Eagles visited the U.S. Geologic Survey (USGS), Menlo Park, CA on 20 August 1976 where they met with L. J. R. Muffler. The USGS geothermal program was discussed as well as the interaction between the Geologic Division and the Water Resources Division (see below). The only geothermal programs undertaken by USGS in Region 5 were in Florida and Virginia. However, there are data on down-hole temperatures for the Atlantic Outer Continental Shelf oil and gas wells; APL will make a formal request for these data. An extremely vexing problem at USGS, Menlo Park is the management of data and data bases. Some bases are redundant, some are competing with others, and some are incompatible. However, a most useful overview of the USGS/ERDA program was obtained, even though much of it does not pertain directly to Region 5.

Visit to USGS, Water Resources Division, Denver

An APL representative visited A. Clepsch and R. Blankennagel of the USGS Water Resources Division (WRD) in Denver, CO on 1 September 1976 to discuss their study of the hydrology of the Madison limestone formation.

The Madison study was undertaken to collect sufficient data to permit the development of a quantitative description of the hydrology of the Madison limestone formation. Reference 1 outlines the study plan; Ref. 2 illustrates the desired quantitative output of the study. The Madison is a porous limestone that carries water; however, in northern North Dakota it also carries oil and gas. The formation underlies all of parts of the states of Montana, Wyoming, North and South Dakota, and Nebraska. The quantitative description (see Ref. 2) for typical results) will be in the form of a digital simulation of the aquifer and interconnecting shallower aquifers in the Fall River and the Dakota sandstone formations. By means of the simulation, the effect of water being removed from the formation can be studied. The impetus behind the USGS study is the need for water in the development of the extensive coal resources in Montana and Wyoming. Montana has surface water (the Yellowstone and Missouri Rivers), but Wyoming has very little. The planned coal developments include steampower generation, gasification, liquefaction, and a slurry pipeline to Arkansas.

The Madison study will take at least five years to complete and will cost at least $12 million. The study can be used to analyze the geothermal use of these waters where they are found at moderate temperatures (see Ref. 3).

Items of interest not discussed in Refs. 1 and 2 are:

1. USGS WRD has purchased well logs from an association of gas and petroleum companies for all of the exploratory oil and gas holes and producing wells in the area. Titles of geothermal reports obtained by APL were supplied to USGS; data obtained in the future on temperature, chemical analysis, and shut-in well pressure will also be forwarded.
2. USGS is drilling a well near Devil's Tower, Alzada Mountain, in the northeastern corner of Wyoming. This well will be approximately 4400 ft deep and will be drilled 50 ft into Precambrian basement rock. The cost of this well will be more than $700 000. Currently the drill stem has been lost at 2300 ft, so cost overruns are expected. The temperature at the 2300 ft depth is 103°F. The well is expensive since it has blowout prevention and a 20-in. bore to the Minnelusa formation. Individual aquifers are to be located and sealed (cased and cemented) and cores are to be taken at areas of interest to USGS WRD. Cores of the formation and basement rock are planned. No radioactive isotope or thermal conductivity measurements are planned although a gamma spectroscopy log of the hole will be made. The hole is expected to be finished in October 1976. A second hole in East Central Mountain in the Powder River Basin will be drilled 10 000 ft into basement rock. Once again, a 20-in. initial hole is planned. The expected cost of this hole is $2 million; drilling is expected to take 160 days. A third well in the center of the Powder River Basin is being drilled by Getty Oil. The hole will go into the Madison formation at 16 000 ft. No one knows how deep the basement is located, since oil exploration holes usually do not go into the basement rocks.
3. USGS WRD plans to date the water samples by radioactive carbon techniques.

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4. USGS WRD plans to measure the lateral aquifer water velocity of two wells along a flow line by radioactive carbon techniques. Temperature is an important parameter in the model as it significantly increases the lateral flow velocities because of reduced viscosity. USGS WRD does not care why the water is hot, only its location and temperature.
5. Hydrostatic pressure is an important parameter that USGS thinks should be measured accurately.

The USGS study will have a pronounced effect on South Dakota's understanding of its thermal waters.

ERDA should consider joining the USGS in this study, becoming first a member of the Liaison Committee. Further ERDA should consider requesting cores from the basement rock of the two holes that were measured for radioactive isotope concentrations and thermal conductivity. The overburden, i.e., sedimentary cover, should also be studied.

References

1. "Plan of Study of the Hydrology of the Madison Fine Stone and Associated Rocks in Parts of Montana, Nebraska, North Dakota, South Dakota, and Wyoming," USGS Report 75-631.
2. "Preliminary Digital Model of Ground-Water Flow on the Madison Group, Powder River Basin, and Adjacent Areas, Wyoming, Montana, South Dakota, North Dakota, and Nebraska," USGS Water Resources Report 63-75.
3. "Geothermal Energy and South Dakota," APL/JHU QM-76-107, 26 August 1976.

Visit to Virginia Polytechnic Institute

On 2 July 1976, a visit was paid to Virginia Polytechnic Institute to discuss with J. Costain and Lynn Glover their work on the ERDA/DGE. A. M. Stone, J. W. Follin, Jr., and F. C. Paddison were informed of conductivity measurements in the Piedmont area of the Appalachians. We also learned of their work during the summer of 1976 in the Virginia Hot Springs area, as well as of plans to investigate conductivity in the Charleston, SC, area during the USGS drilling project.

GEOTHERMAL HANDBOOK

A rough draft of a Geothermal Handbook has been completed. The Handbook consists of three parts:

1. A glossary of approximately 500 terms chosen from the geothermal literature, defining the geological, physical, and engineering terms that most frequently occur.
2. A set of fact sheets that discuss in essentially a one-page format such subjects as geothermal gradients, rock classification, and geological time scales.
3. Conversion tables for the physical quantities of interest for energy research in general and geothermal research in particular.

In its present form, the Handbook doubtlessly contains omissions, inconsistencies, and errors. Following editing and review, the Handbook will be published for the use of those interested in this field.

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TECHNICAL STUDIES

Heat Pumps and Geothermal Energy

One of the most important aspects of using geothermal energy is user/resource matching. The temperature and energy requirements of a potential user must be matched with the temperature and energy output of the geothermal source. Although a geothermal source may have more than enough energy or power output for a particular user, the geothermal output temperature may be too low. One method of overcoming the problem is through the use of heat pumps. Another problem for any geothermal source not hot enough to be useful for the generation of electricity is transporting the low-grade energy to the site where it can be used.

Two types of pumps that can possibly be driven using energy from the geothermal source itself, as opposed to pumps requiring external shaft power, are turbine compressors (Ref. 1) and Stirling engine-Stirling heat pumps. A type of device that can be used to transfer energy over large distances either for the purposes of space cooling or space heating is a chemical heat pump. An interesting paper addressing the first device was given by D. T. Neill (Ref. 1) at the 11th Intersociety Energy Conversion Engineering Conference meeting in September 1976.

The energy requirements of the turbine-compressor described in Ref. 1 assume a 150°C (302°F) saturated geothermal fluid. Neill assumes that the compressor is 90% efficient and the steam turbine 75% efficient.

The Stirling engine-Stirling heat pump concept has not been proven (and therefore is in the same category as the other two systems). The major question is: Can a Stirling engine extract and output reasonable energy between heat sinks with a ΔT_{op} (change in operating temperature) of 100°C?

N. E. Polster, the inventor of the Polster Stirling engine, has a demonstration model that does operate with a ΔT_{op} as little as 100°C. Polster believes that such a Stirling engine can be built.

W. Bealle of the University of Ohio has made a tentative study of the feasibility of a Stirling engine driven with a ΔT_{op} of 100°C. He believes that an engine can be built that has an efficiency of 50% of Carnot efficiency. He sees no physical limitations on the size of a Stirling engine. However, economic factors probably limit the maximum power output to 100 kW/cylinder. Greater power requirements would be achieved more economically by multiple units.

G. Benson of ERG Inc. indicated that they are working on a Stirling engine-Stirling heat pump combination suitable for geothermal application.

It appears technically feasible for Stirling engines to operate with a ΔT_{op} of 100°C, but the economics of such devices have not even been discussed.

The following should be noted relative to heat pumps. W. Bealle has modeled various heat pumps to find which is most efficient as a function of ΔT_{hp} (the difference between heat pump output temperature and heat pump input temperature). His results indicate that for values of ΔT_{hp} less than 60°C, the Rankine cycle heat pump is more efficient than a Stirling cycle heat pump. For values of ΔT_{hp} greater than 60°C, the Stirling cycle heat pump is better.

A chemical heat pump uses "exothermic mixing," a process in which certain pairs of substances give off heat when mixed. Some examples of chemical pairs are NH_3 and H_2O, LiBr and H_2O, $CaCl_2$ and H_2O, $CaCl_2$ and NH_3, and H_2SO_4 and H_2O. Heat is used to separate the chemical pairs. This heat can be recovered when they are mixed together. Also, they can be used for cooling in an "absorption air conditioner."

One great advantage of the chemical heat pump is that the substances can be piped long distances before recombination. Thus thermal energy can be transported for long distances "chemically," without "thermal loss." Also, remote geothermal sources can be used whose temperatures are too low to generate electricity efficiently.

Reference

1. D. T. Neill, "Geothermal Powered Heat Pumps to Produce Process Heat," 11th IECEC Proceedings, Vol. I, pp. 802-807.

The Use of Extremely Low Frequencies to Measure Earth Conductivity at Depth

It is known that most geothermal resource regions are characterized by their high electrical conductivities (about 1 mho/m). In the past, magnetotelluric (MT) methods have been used to probe the conductivities (or equivalently, the resistivities) of the underlying layers (Refs. 1 and 2). The MT methods measure the tangential E and H fields and infer the "surface" impedance tensor defined by $H_{\parallel} = ZE_{\parallel}$, where $E_{\parallel}$ and $H_{\parallel}$ are the surface fields (two components). In the one-dimensional model, the impedance is a function of the frequency and the conductivities of the underlying layers. Hence the measurements at various frequencies lead to a determination of the conductivities.

Past MT investigations (for example, Ref. 1) used the MT fields in the frequency region of 10^{-4} to 10 Hz, probing the depths down to about 10^3 km. Unfortunately, the MT signals are not coherent, rendering the required signal processing quite cumbersome. On the other hand, at the extremely low frequencies (ELF) (say, 45 to 75 Hz), the skin depths are typically in the neighborhood of 2 km (1.8 to 2.4 km); consequently, the EM signals in this region are ideally suited for probing the near-surface underground conductivities to about 3 km. Fortunately, there is a U.S. Government-owned facility that radiates coherent signals at 45 and 75 Hz.

To demonstrate the feasibility of the application of such a signal to the detection of the localized regions of anomalously high electrical conductivity, a study is in progress to calculate the horizontal components of the electric field and also its phase at the surface in highly conductive regions. The results obtained indicate that the fields reflected off such regions (buried 1 to 2 km deep) may be detected at about 10 to 15 km by means of a phase-sensitive receiver system. This work is being documented and is expected to be published during the coming quarter. Thus, on the basis of the preliminary results it is believed that subterranean conductivity probing using the ELF/MT methods will be feasible.

References

1. See for example, D. R. Word et al., "Crustal Investigations by the Magnetotelluric Tensor Impedance Method," Geophysical Monograph Series, Vol. 14 (J. G. Heacock, Ed.), American Geophysical Union, 1971, pp. 145-167.
2. D. H. Bennett and J. H. Filloux, "Magnetotelluric Deep Electrical Sounding and Resistivity," Reviews of Geophysics and Space Physics, Vol. 13, No. 3, 1975, pp. 197-203.

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY §1
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: DGE/ERDA
F. C. Paddison and R. A. Eisenberg
Status, September 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF SOUTH DAKOTA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States 1975," emphasizes known high-temperature geothermal resources. However, the lower temperature and normal-gradient characteristics of their Region 5 (the central and eastern United States east of the Rocky Mountain states, excluding Texas and Louisiana) are not discussed in detail. We understand that in the future the USGS will revise its reports to include these lower temperature regimes. Currently a survey is being made of Region 5 to develop a basis for predicting the possible use of geothermal energy as a function of time, and to select the subregions for a near-term concentration of planning effort. In that connection, the South Dakota State Geological Survey was visited.

SUMMARY

The western half of South Dakota is underlaid by several extensive aquifers that carry thermal waters. These aquifers are located at depths of from 2000 to 4000 ft, depending on their specific location. The thermal waters are used for space heating in two specific locations.

Considering the northern location of the state and its ready access to the thermal waters, South Dakota appears to be an area where immediate application of geothermal energy is possible on a large scale.

The Water Resources Division of the USGS is studying the waters of one of the aquifers found in South Dakota, the Madison formation; however, additional geothermal studies are recommended as well as studies of other aquifer systems found in the state.

DISCUSSION

In 1974 the South Dakota Geological Survey published "The Geothermal Potentials in South Dakota, Report of Investigation No. 110." The report was discussed with Duncan McGregor and Robert A. Schoon of the State Geological Survey at Vermillion on 18 August 1976. The State Energy Office, the Greater Missouri Community Development Corporation, towns, and individuals in South Dakota either currently using or planning to use geothermal energy were also visited. Reference 1 is a detailed trip report.

There are three deep aquifers extending from the Black Hills and the western edge of the state in an east-southeast direction. These aquifers are termed, in order of increasing depth, the Dakota, the Fall River, and the Madison formations. The first two are composed of sandstone; the last is limestone. The Madison formation is close to the top of Precambrian basement rock. The thicknesses and depths of the aquifer layers vary in most of the western half of the state and their temperatures are higher than would be expected for the normal geothermal gradient. Accordingly, all are potential geothermal sources. At the town of Philip, for example, the water temperature in the Fall River formation is 125°F; in the Madison formation it is 158°F. In the town of Pierre the Dakota formation temperature is 92°F.

There are two places where the thermal waters are being used for space heating: Midland High School and part of the Little Scotchman Industries factory in Philip.

The thermal springs in Hot Springs are used for bathing and in Edgemont for public drinking water. The water temperature is 87°F at Hot Springs and 125°F at Edgemont. There is a report of a well at the town of Igloo, nine miles south of Edgemont, that produced 180°F water.

It is apparent that there is a radiogenic heat source near or in the Black Hills, a domed region where intrusive and metamorphosed sedimentary rocks are thrust upward and granite and schist are exposed. The western half of South Dakota is covered with metamorphic and nonmetamorphic sedimentary rock, 3000 to 4000 ft thick. The Precambrian basement rock forms a gentle syncline over many areas in the western part of the state. The syncline in turn forms a gentle basin whose center is located near Philip. The upward slope of the syncline extends into North Dakota; the downward slope on the other side of the basin extends into Nebraska and Iowa.

The eastern half of South Dakota is covered above the basement rock by a metamorphic sandstone called South Dakota rose quartzite. This rock is not permeable and carries little water.

Neither the interface between the sedimentary west and the metamorphosed east nor what happens to the water from the three aquifers is well understood. The anomalous thermal gradient evidenced in Ref. 2 (and to be discussed later in this report) may well be the thermal waters from the Dakota, Fall River, and Madison formations appearing at shallow depths.

Reference 2 describes unusually high thermal gradients in an area slightly east of the middle and in the southern half of the state. These gradients are compiled from relatively shallow wells. There are no deep wells in the area to supply data on the temperature gradient at depth. Dr. McGregor had proposed that ERDA drill a deep hole, but the proposal apparently was rejected.

A program is under way to use water from the Madison formation on the west side of the Black Hills to pump coal in slurry form from the southeastern coal fields in Wyoming to Gillett and then on to Arkansas. Although South Dakota has entered into litigation over the use of its water to pump coal, no studies have been made to determine possible deleterious effects on the water supply. USGS Water Resources Branch/Denver is conducting an extensive study to obtain more data on the Madison formation; see "Comments on Limited Tasks," elsewhere in this Quarterly.

James Van Loan (Director) and Brian Heisel (Deputy Director) of the South Dakota State Energy Office were not aware of the State Geologist's report on geothermal energy (Ref. 2). The State Energy Office is interested in geothermal energy but is not active in its promotion. They recommended that we meet and talk

with Tom Kuestermeyer, Housing/Winterization Coordinator of the Missouri Community Development Corp. (CDC), who is interested.

Since the State Energy Office is generally concerned with space heating and energy, we promised to send it some tutorial data on the uses of geothermal energy. There are no natural gas pipelines into South Dakota and no coal deposits; heating is done by electricity, oil, or bottled propane gas. The state is near the end of the supply system for oil and gas and is subject to supply shortages. One-third of the state is comprised of Indian reservations and constitutes a unique socio-economic-institutional problem for which solar and geothermal energy constitute a promising solution.

We met briefly with Mr. Kuestermeyer, who is responsible for the alternate energy and area winterization program. Although he is not an engineer, he would welcome practical information on geothermal energy and how to apply it. He had previously called J. Bresee of ERDA for help. CDC is quite concerned with the area and plans to help in its development. They are currently administering a program called "winterization" that supplies storm windows and insulation to people in need.

St. Mary's is a secular hospital run by the Dominican Sisters. Arthur Thomas, Hospital Administrator, called Clayton Nichols to request help on how to convert the hospital to use geothermal energy. Dr. Nichols gave his name to F. C. Paddison of APL and to Mr. Donovan of the Idaho International Energy Lab. (INEL), who visited the hospital. The hospital oil bill, $60 000 last year, has doubled in the last several years, and further rises are anticipated. Also, since the two furnaces must be replaced within two years, they would like to convert to a less expensive and more assured energy system. The hospital has hired a consultant engineering firm to examine and design geothermal and alternate heating systems. A report is due in November 1976.

The State Geologist told Mr. Thomas that the Madison aquifer would serve his needs and, based on the data from the satellite-airport well drilled into the formation, that thermal water probably would not exceed 110°F.

The town of Murdo has just made three attempts to drill wells to replace the municipal water supply previously obtained from ground runoff. (1976 was a drought year; with water in short supply, the town decided that a well is necessary. The State Geologist and Water Resource Branch of USGS suggested that the Madison formation would be an ideal source of water.) The first hole drilled was not finished because of difficulties with the drill stem and casing. The second hole went down to the Fall River formation; since it did not look promising, it was extended into the Madison. However, the head was 50 ft too short so the water had to be pumped out. A third hole, one-half mile away, was drilled 3313 ft deep to the Madison formation. Water from this well flowed at a rate of 120 gal/min at 130°F but the flow has recently decreased to 90 gal/min. The log for the well indicates that the thickness of limestone is less than 100 ft compared with 300 to 400 ft at Pierre and Midland. There were no plans for the use of thermal waters at Murdo other than to augment the runoff water collected for the town water supply.

Midland, a town of 500 enterprising people, could be a model for ERDA. In 1907, the local railroad drilled wells in nearby towns and found hot water at 118 and 120°F that was used to provide hot mineral baths for travelers. In 1939 the Stroppel family drilled a 1784-ft well into the Dakota formation and used the water for the hotel's two mineral baths. Water from this well originally flowed at 30 gal/min at 116°F; currently the flow is about one-half that and the temperature is 112 to 114°F. The water is not used after it exits from the baths.

Fifteen years ago, the town of Midland drilled a well into the Madison formation in order to obtain drinking water. Seven years ago the well casing failed and a new well 3100 ft deep was drilled into the formation. Some of its water is used to heat the school and the school administration building. It is then used, together with the balance of water from the well, for the town water supply. The school and the administration building have identical geothermal heating plants. Two heat exchangers are in each building.

One of the original 15-year old heat exchangers was replaced recently because the waters are very corrosive. The water is used for drinking although home water softeners are necessary. Town water costs $6 per month for an unlimited amount.

The town of Philip uses the water from two wells obtained from thermal aquifers. The town water supply is obtained from a 3730-ft well drilled into the Madison formation that produces water at 2000 gal/min at 158°F. The other well, drilled by the owner of Little Scotchman Industries, is into the Dakota formation. The well is 2600 ft deep and produces water at 125°F. It was drilled several years ago at a cost of $12 500. The water is used to heat parts of the industrial buildings and the owner's home.

REFERENCES

1. F. C. Paddison and R. A. Eisenberg, "Geothermal Energy and South Dakota," APL/JHU QM-76-107, 26 August 1976.
2. R. A. Schoon and D. J. McGregor, "Geothermal Potentials in South Dakota, Report of Investigation No. 110," South Dakota Geological Survey, 1974.

F. C. Paddison, R. A. Eisenberg, and A. M. Stone
Status, September 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF NEW HAMPSHIRE

As part of the Energy Research and Development Administration (ERDA) Geothermal Research Program for their Region 5 (the central and eastern United States east of the Rocky Mountain states, excluding Texas and Louisiana), a joint program was initiated with the State of New Hampshire, Los Alamos Scientific Laboratory (LASL), and the U.S. Geological Survey/Denver to investigate the Conway granite layer found in northern New Hampshire. Conway granite is considered to be unique, having a high concentration of radioactive species. A hole was drilled 4000 ft into the Conway granite to measure the temperatures at various depths. These measurements will be compared with a series of logs from other holes, and petrology studies will be undertaken. The drilling of the 4000-ft hole in the Conway granite was completed, and portions of selected cores were forwarded to LASL for analysis of the radioisotopes.

DISCUSSION

A visit to Glen Stewart, the State Geologist, was made on 17 August 1976 to discuss the status of the Conway granite program and the geology of the state.

According to Mr. Stewart, there are two phases of New Hampshire geology: the intrusives and the extrusives or pyroclastics. In New Hampshire the more basic rocks were intruded first; the more alkaline intrusives, which extend into Quebec, were intruded later. Alkali intrusives are dated as late Triassic to early Jurassic (150 to 200 million years old). The basics have not been dated but from cross-cutting relationships they have been shown to be older. The pyroclastic phase includes detrital volcanic vent. Ring dikes, like those in New Hampshire, are usually related to pyroclastic volcanism and are produced by underground cauldron subsidence. Cauldron subsidence results from the lowering of a steep ring fracture of a roughly cylindrical block into a magma chamber. The blocks of the roof as well as country rocks may sink to a great depth where they are assimilated by the actions of hot magma. The magma can gradually penetrate upward into the country rock. Some ring-dike complexes have a central block of volcanic rocks that have subsided; others have what is known as a "central stock," which usually consists of granite. The alkalic stocks and batholiths of New Hampshire are composite complexes made up of ring dikes and stocks that have attained their positions of ring fracture stopping in the upper level of the crust.

Mr. Stewart did not know of any Precambrian shield rocks in New Hampshire. Most of the volcanics in the northern part of the state are relatively young. Potassium-argon dating places the age of the Conway granite as Mississippian (280 million years old). Although the volume of Conway granite is unknown, its area has been estimated at approximately 300 square miles. Since the time of the granitic intrusions, only slight tectonic forces have been at work. Most of the deformation that occurred during Appalachian mountain building was prior to intrusions of the granite (in the Devonian). In the geologic past, the state was covered by a thick sedimentary pile that has now been removed by erosion, leaving the large area of quartz-rich gneisses extensively exposed in the southern portion of the state.

After discussing general New Hampshire geology, the recent drilling in the Conway granite was considered. A 2-7/8-in. hole was drilled in the granite to a depth of 3000 ft at an average cost of $30/ft. Drill cores were made over the entire distance. A low gamma count was present from the surface to a depth of 1000 ft. From 1000 to 2500 ft the count doubled, except at 2000 ft where a dioritic dike caused the gamma count to fall drastically. Below 2500 ft, syenite, an igneous rock, was encountered which proved to be less radioactive. Syenite contains no quartz but otherwise has about the same composition as granite. Drilling stopped at the syenite since the main objective of the program was to measure the radioactivity of the Conway granite.

The Conway granite was found to be very hydrothermally altered at a depth of 500 ft. It is possible that this may have been a shear zone and that hot fluids escaped through the shear, producing alteration. The altered portions of the core, unlike the rest of the Conway granite, are tremendously absorbent. No heat-flow or conductivity measurements were made in the Conway hole; however, heat-flow measurements made by Birch, Ray, and Decker on the Conway granite are mostly average, with the greatest being double the average.

Geothermal Potential of New Hampshire. Does the Conway granite underlie the sedimentary cover (3000 ft deep) in lower New Hampshire? Are the exposed areas of granite good enough conductors to dissipate the heat in the Conway granite if it does extend under lower New Hampshire? There are no drill holes in southern New Hampshire through the sedimentary cover. We will ask in other New England states whether data exist that can answer these questions.

Further geothermal energy studies of the Conway granite in the drilling location are probably not warranted since the gradient is so unfavorable. Only if the answers to the above questions are favorable should geothermal scenarios for New Hampshire be seriously considered.

REFERENCE

1. F. C. Paddison and R. A. Eisenberg, "Geothermal Energy and New Hampshire," APL/JHU QM 76-108, 27 August 1976.

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY DEVELOPMENT AND UTILIZATION §3
Geothermal Program, Region 5 ZJ70CQO
Support: DGE/ERDA

F. C. Paddison and R. A. Eisenberg

Status, September 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF FLORIDA

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources," emphasizes known high-temperature geothermal resources. Accordingly, the lower temperature and normal gradient characteristics in the U.S. Energy Research and Development Administration's Region 5 (the central and eastern United States east of the Rocky Mountain states excluding Texas and Louisiana) are not discussed in detail. We understand that the USGS will revise its report to include lower temperature systems. Until then, a survey of Region 5 is under way to develop a basis for predicting possible utilization of geothermal energy as a function of time and to select the subregions for near-term concentration of planning effort. For these reasons, the Florida State Geologist's Office in the Department of Natural Resources and the State energy offices were visited.

SUMMARY

Reference 1 is a study funded by the Florida Power and Light Company and performed by personnel from Florida State University with limited assistance from the State Geologist's Office. The study was of an area where dense urban development is expected in the future and where there is little detailed geology or drill-hole data. Based primarily on gravity data, the study asserts that Florida may be an area with a greater-than-normal thermal gradient and that the drill-hole temperature data that are available from areas in the state may be low because of the lateral flow of cooler shallow aquifers.

The State Geologist's Office considers the referenced report a reasonable assemblage of data; however, they do not feel that the conclusions are warranted. W. Oglesby, Staff Geologist, felt that the gravity data are well founded and should be published alone. The State Geologist's Office is presently compiling a report on geothermal energy potential from a statewide point of view. The report will include some of the data apparently with different conclusions or qualifications.

The State Energy Office and the Department of Natural Resources are not optimistic that there is any geothermal potential in the State other than the normal increase in temperature with depth.

DISCUSSION

Meetings were held with Damon Agee (Director), and William W. Goode, Jr. (Administrator) of the State Energy Office. The Office was not aware of the referenced report, and Mr. Goode was sure there was little hope for anything other than normal gradient heat in Florida. There has been oil production in the Florida Panhandle and in lower south central Florida. The wells are near depletion and temperature gradients are normal — 250 to 265°F at 12 000 ft. The Texas geopressured region extends under a small portion of northwest Florida. Mr. Goode discussed several problems encountered by deep-hole drillers in Florida that make the cost of deep drill holes comparatively expensive, i.e., approximately $750 000 for a cased, cemented 11 000-ft hole. Shallow holes also tend to be expensive, costing on the average $80 000 for a 5000-ft hole for drilling alone. One reason is that much of the rock is hard, dolomite and limestone, and penetration rates are slow. Also contributing to the high cost of drilling is the fact that most of the Florida platform is composed of calcite or evaporites that are easily dissolved by underground waters, resulting in the formation of large cavities or caverns. When these are encountered, drilling mud is lost and water must be used as a lubricant. Finally, the well casing cannot be cemented in; therefore there is usually vertical circulation between aquifers (due to differential pressures) and temperature logs are distorted.

The State buildings in Tallahassee use a shallow, low-temperature aquifer to cool air-conditioner water. The cooling water is not used again.

Discussions were held with personnel of the Florida Department of Natural Resources; State Geological Survey; C. W. Hendry, Bureau Chief and State Geologist; W. Oglesby, Staff Geologist; and S. R. Windham, Assistant Bureau Chief.

Mr. Hendry and Mr. Oglesby acknowledge that, to their knowledge, there is little other than normal gradient in the Sarasota/Charlotte, Florida, area or the State in general. The higher-than-normal temperatures referred to in the report were for shallow water and, according to the State Geologist, could be caused by anomalous movement of warm water. Mr. Hendry also stated that he was not sure how the temperature data were obtained. He seemed a little suspicious of the results. According to Mr. Windham, it is common to get shallow anomalies because of different pressures in aquifers and the difficulty in cementing casings in Florida. Accordingly, they do not necessarily represent any thermal irregularity at greater depth.

There are many deep holes in Florida. We studied data for a hole near the locale discussed in Ref. 1. The bottom-hole temperature was 265°F at 12 000 ft and, for a hole near Miami, 250°F at 12 000 ft. Much of our meager knowledge about crystalline basement rocks in Florida has been obtained from oil test holes. According to the State Geologist, there are rhyolite and basaltic rocks beneath the sedimentary pile. North of Panama City there are Triassic granites that supposedly have been

traced into Georgia. Mr. Hendry noted that igneous basement rocks reached by drilling may, in fact, be dikes since they were not penetrated. It is standard procedure for exploratory oil drilling to stop once crystalline rock is hit, since there is no possibility of finding oil. The shallowest basement rocks are 5000 ft deep in north central Florida. An age of 180 million years has been given to the igneous activity, both basaltic and granitic, in Florida.

REFERENCES

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2. F. C. Paddison and R. A. Eisenberg, "Geothermal Energy and Florida," APL/JHU QM 76-105, 10 August 1976.

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OPERATIONAL RESEARCH, GEOTHERMAL ENERGY §4
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: DGE/ERDA
F. C. Paddison and R. A. Eisenberg
Status, September 1976

STATUS OF GEOTHERMAL ENERGY IN THE STATE OF ARKANSAS

The U.S. Geological Survey (USGS) Circular 726, "Assessment of Geothermal Resources of the United States 1975," emphasizes known high-temperature geothermal resources. Although the lower temperature and normal-gradient characteristics of the U.S. Energy Research and Development Administration's Region 5 (the central and eastern United States east of the Rocky Mountain states, excluding Texas and Louisiana) are not discussed in detail, we understand that the USGS will include lower temperature resources in its future reports. Until such reports become available, a survey has been undertaken in Region 5 to develop a basis for predicting the lead time necessary before geothermal energy can be utilized, and to select subregions for concentrating planning efforts. To that end the Arkansas State Geologist's Office and the Hot Springs National Park were visited on 5 August 1976.

SUMMARY

Arkansas appears to have only one known geothermal source other than the normal thermal gradient. The source is a series of springs located in the west central part of the state from which approximately one million gal/day of 140°F water emerge. The springs and much of the surrounding area are contained in the Hot Springs National Park, administered by the U.S. Park Service (USPS) under the Department of the Interior.

The USPS will soon propose a major modification to the present water policy that should revitalize parts of the Park and allow better use of its thermal resources. Among its proposals is a plan to extend the use of the thermal waters for space heating to include the Park bathhouses.

On the assumption that all the U.S. Park Service plans are realized, there will probably be thermal waters available for other purposes as well. It is entirely possible that use of the thermal waters can be extended without endangering the hot springs.

DISCUSSION

A discussion was held with the State Geology Office and representative personnel of the USGS Water Resources Bureau on 5 August 1976. Present were Normal F. Williams, Director of the Arkansas State Geologist's Office, Drew Holbrook, Acting State Geologist, O. A. Wise, Office of State Geologist, and R. T. Sniegocki, USGS Water Resources Geologist.

According to Mr. Sniegocki and Mr. Holbrook, the only known potential geothermal resources in Arkansas are located at Hot Springs. A report published by the USGS in 1975 (Ref. 1) was discussed with them. Its purpose is to describe the spring system, consider the effects of urban development on the springs, and guide the USPS on where to buy land to preserve the recharge of the thermal springs.

Hot Springs National Park is located in the Zigzag Mountains. In 1832 the government made an area of about 4 mi^2 a federal reservation; since then it has been maintained by the USPS. In recent years the Park Service has been buying land proximate to the Park. They hope for Congressional approval to purchase additional land to preserve the recharge of the streams and maintain good water quality.

Geologically the Zigzag Mountains are composed of intensely folded, overturned, and faulted rocks ranging in age from Ordovician to Mississippian. The 47 hot springs issue from the crest of a southwest anticline. All the springs are emitted from a very porous formation known as Hot Springs Sandstone between two thrust faults. According to Mr. Sniegocki, the alignment of these springs, which cut across the folds, suggests that an extensive fault system may be present. Besides the Hot Springs Sandstone, other rocks in the area include cherts, shales, and novaculites. Novaculite is a very tough, even-grained white chert consisting of cryptocrystalline and microgranular quartz. Although the novaculite is older, it overlies the local sandstone as a result of folding and overturning, the intensity of which produces extensive jointing and fissuring. According to Mr. Sniegocki, the joints and fissures provide conduits for water to recharge the aquifer.

Surface spring temperatures at Bathhouse Row are approximately 140°F; the temperature of normal ground water in the area ranges from 60 to 65°F. Silica geothermetry indicates that a convective heat-transferring cycle must be present. The temperature of the springs has not always been constant. A 0.6°F cooling in the last 10 years has been reported. Total flow of the hot springs ranges from 750 000 to 950 000 gal/day. Seasonal fluctuations of the flow correspond to the annual climatic cycle.

Chemically, except for silica, the hot springs are low in dissolved minerals. Concentrations of dissolved solids are approximately 200 mg/l. Except for the high concentration of silica in the hot springs, cold springs in the area are almost identical in chemistry, both having high concentrations of radon. The source of radon is unknown, and the water has not been analyzed for the presence of other radioactive elements. The spring's water is considered to be meteoric in nature, with an age of 4400 years, with a small amount of younger water. The annual rainfall is 55 in., and it is assumed in a USGS hydrodynamics model that 2 to 6 in./yr of the rainfall from recharge areas leak down 2000 to 8000 ft where the water is heated and returned to the surface by convection. Silicon chemistry indicates that the temperature at depth is not significantly different from the temperature at the surface.

The heat source for the springs is unknown. Some sources speculate that the thermal springs are heated by a higher-than-normal gradient. No reliable gradient measurements or bottom-hole temperatures exist to prove or disprove this hypothesis. Because of the presence of large amonts of radon in the springs, it is possible the heat source may be radiogenic. Mr. Sniegocki and Mr. Holbrook tend to favor a

completely normal gradient, the waters being heated by deep circulation through folded structures. There is also the possibility that the waters are heated as igneous rocks cool. Although the area is predominantly sedimentary, igneous intrusions such as dikes and sills are present in the vicinity of the discharge area. The dikes are mostly small, ranging from 3 to 10 ft in width. One diamond-pipe dike in Murphysburg, in the southwestern region of the state, has been privately mined for vanadium. However, the mine was only superficial and no unusual temperatures were noted.

The springs are almost entirely used for balneological purposes. Approximately 11% of the water is used for the park bathhouses. Less than 1% is being used to heat the Park Service building by means of a heat exchanger. The rest is not used.

The Arkansas Geological Survey has proposed to the USGS that three holes be drilled in the area of the springs, one to a depth of 3000 to 4000 ft and the other two to 500 ft. The Arkansas Geological Survey, in cooperation with the USGS, plans to obtain water and core samples as well as heat flow and conductivity measurements at various depths so that a better assessment can be made of the area's geothermal potential

There are many springs and drilled wells in the area. Most wells are shallow, ranging from 50 to 200 ft. There are several 200-ft wells fairly close to the 47 hot springs. These wells produce water with temperatures ranging from 72 to 90°F. One well, drilled at the State Rehabilitation Center very close to the hot springs and Bathhouse Row, is 336 ft deep. It was temperature-logged and showed a high-temperature (134°F) aquifer from 140 to 220 ft in a sandstone formation. There is a 1000-ft-deep Fordyce well in the middle of the hot artesian springs and along the fault line, the suspected exit path for the heated waters. No data from this well were discussed.

In summary, the hot springs represent such a large, under-used geothermal source that they tend to stifle any consideration of other potentials in the state. Their closeness to a town also argues for their use ahead of more difficult developments and engineering applications elsewhere in the state.

A discussion was held with Bernard Goodman, Superintendent of Hot Springs National Park. According to Mr. Goodman, thermal waters are collected and stored in a 100 000 gal tank at an average temperature of 140°F. Approximately 11% of the waters are kept under pressure to keep radon gas in solution and are sent through a heat exchanger and sold to the bathhouses. During the winter a small amount of the water from the springs is used to heat the Park Headquarters. Even though they are low in dissolved minerals, the waters deposit minerals when temperature changes are substantial. Accordingly, the life expectancy of the heating system heat exchanger is 30 years, and all plumbing is designed for easy replacement. A future objective is to add geothermal heating to all bathhouses.

The USPS has a long-term plan for revitalizing Hot Springs National Park and the adjacent town. The plan is in draft form and will be published in two parts as a general management plan and an environmental statement. The reports will not be available until July 1977; however, a copy can be obtained from Ray Freeman, Assistant Director of Development, or Gerald Patton, Chief, Environmental Quality, in Washington, DC.

REFERENCES

1. U.S. Geological Survey, "The Waters of Hot Springs National Park, Arkansas, Their Origin, Nature, and Management," USGS, 1975.
2. F. C. Paddison and R. A. Eisenberg, "Geothermal Energy and Arkansas," APL/JHU QM 76-104, 18 August 1976.

OPERATIONAL RESEARCH, GEOTHERMAL ENERGY §5
DEVELOPMENT AND UTILIZATION
Geothermal Program, Region 5 ZJ70CQO
Support: DGE/ERDA
C. A. Shipley
Status, September 1976

INITIAL SCENARIOS

A major task of the U.S. Energy Research and Development Administration (ERDA) Geothermal Project is to prepare a nonelectrical energy development and utilization scenario for specific geothermal resources in ERDA Region 5 (the central and eastern United States east of the Rocky Mountain states, excluding Texas and Louisiana). Because most potential sources and users are unique, a decision was made during early planning to develop initial scenarios for some specific sources and their potential users. After a survey of some known geothermal sources in Region 5, it was determined that Hot Springs, Arkansas (population of about 30 000), was a logical starting point. The preliminary scenario will concentrate on space heating and air conditioning of buildings.

The area has a series of moderate-temperature springs located nearby in Hot Springs National Park. The water is relatively clean, with a seasonally varying flow of 750 000 to 950 000 gal/day at about 140°F. The flow has been reliable for at least the past 100 years, although the temperature has dropped about 0.6°F over the past 10 years. At present, 11% of the total flow is used by eight commercial bathhouses in the National Park. Less than 1% of the flow is used to heat the National Park Service Administration Building. The remainder is not used.

DISCUSSION

Five scenarios (A through E) for Hot Springs development have been provisionally identified. They are listed below, together with their ratings as to probable technical success, cost, and difficulty with respect to incentive, legal, administrative, and environmental considerations.

A. Low risk, low cost, low degree of difficulty — The Park Administration Building is now being heated with geothermal water. Extended geothermal heating capability is proposed by the U.S. Park Service to all other buildings within the Park. This should use 8 to 10% of the total flow in the winter.

B. Moderate risk, moderate cost, low degree of difficulty — Add summer cooling, fueled by geothermal energy, to buildings in the Park in the form of a lithium bromide/water absorption cycle.

C. Low risk, high cost, high degree of difficulty — Extend the heating system to nearby public buildings and/or private homes in the city of Hot Springs. This would use all of the available 89% of the total flow.

D. High risk, high cost, high degree of difficulty — Combine a cooling system with the extended heating capability as described in C above. This might involve heat pumps and some seasonal energy storage system such as lithium bromide/water, ammonia/water, or water/ice.

E. High risk, high cost, high degree of difficulty — Drill for more sources, either heated water or hot dry rock, in the same area. This might involve environmental, legal, and policy obstacles as well as very advanced technology.

Unless new sources in the same area are developed (Scenario E), it is clear that the ultimate energy use will be source-limited. For example, the hot springs can supply 3.7×10^8 Btu/day for space heating (during seven months of the year). This is enough to meet the heating requirements of about 840 average homes in the town. For air-conditioning purposes (during five months of the year), the hot springs can supply about 5.4×10^8 Btu/day. This represents a total energy use of about 1.7×10^{11} Btu/yr.

FUTURE PLANS

During the next quarter, the five scenarios will be developed and the rate of utilization development will be estimated with a time scale for each scenario.

There are several options for each scenario. Generally, they include (a) energy storage in order to average the demand over the year (or day); (b) the buildings (public, industrial, or residential) that can use the energy best; and (c) augmentation of the geothermal energy with conventional fuel systems during times of peak demand to reduce initial system costs.

Development of the scenarios will include detailed analysis and optimization of the various options and must take into account and be consistent with present National Park Service plans for the area.

REFERENCE

1. F. C. Paddison and R. A. Eisenberg, "Geothermal Energy and Arkansas," APL/JHU QM 76-104, 18 August 1976.

ENERGY PRODUCTS §6
Ocean Thermal Energy Conversion F9G AEO
Support: U.S. Maritime Administration, Dept. of Commerce
E. J. Francis and G. L. Dugger
July-September 1976

MARITIME ASPECTS OF OTEC PLANT-SHIPS

Ocean Thermal Energy Conversion (OTEC) plant-ships will use the temperature difference between the surface layer of a tropical ocean (83°F) and the water from the 2500-ft depth (40°F) as the source and sink for a Rankine cycle engine to generate electric power. Because the oceanographic conditions most favorable to both heat engine performance and system cost are found far from U.S. shores, the power will best be used at sea to produce ammonia (75% of which is used for fertilizers to grow corn and wheat), liquid hydrogen, aluminum, or other energy-intensive products for shipment to shore. The ammonia also could be used as a carrier of hydrogen (i.e., it could be decomposed on shore) for fuel cells to generate electricity. This report summarizes results of an investigation of the maritime aspects, including technical and economic feasibility, of OTEC plant-ships, from which it is concluded that rapid development and commercialization (by 1982) of such plant-ships can be done and merits priority government support.

SUMMARY

Figure 1 shows the design concept developed in Ref. 1 for a 100-MW_e(net), demonstration-size OTEC/ammonia plant-ship that would "graze" in the Atlantic Ocean at a speed of 0.5 kt approximately 300 nmi east of northern Brazil. The electric power would be used on board to produce hydrogen by water electrolysis, nitrogen by air liquefaction, and ammonia by synthesis from these gases as shown schematically in Fig. 2. The platform is a concrete barge of 196-ft beam, 476-ft length, and 80-ft draft. It is symmetric about a centrally located, 60-ft-diameter by 2500-ft-long, reinforced-concrete, cold-water pipe (CWP) as shown in Fig. 1. Cold water is pumped by 19 pumps in the top of the pipe to head ponds along the centerline fore and aft over the condensers. Warm water is pumped from port and starboard intakes 25 ft below the surface to 20 separate evaporator head ponds. The condensers and evaporators are arrays of large-diameter, multipass, aluminum tubes housed in open compartments formed by the ship's structure. The seawater flows by gravity through the heat exchangers and out the bottom of the ship. The working fluid is ammonia, which is evaporated, expanded through the power turbine, and recondensed in a continuous cycle. Biofouling of the heat exchangers would be cleaned periodically by running cleaning heads with high-pressure water jets between the tube rows, without interrupting the operation.

This approach integrates simple, readily accessible, and cleanable aluminum heat exchanger modules with a simple, modular concrete hull and CWP that are specifically designed to operate in the most favorable tropical ocean regions where the available temperature difference is highest and the winds, waves, and currents are smallest. Thus it is believed to

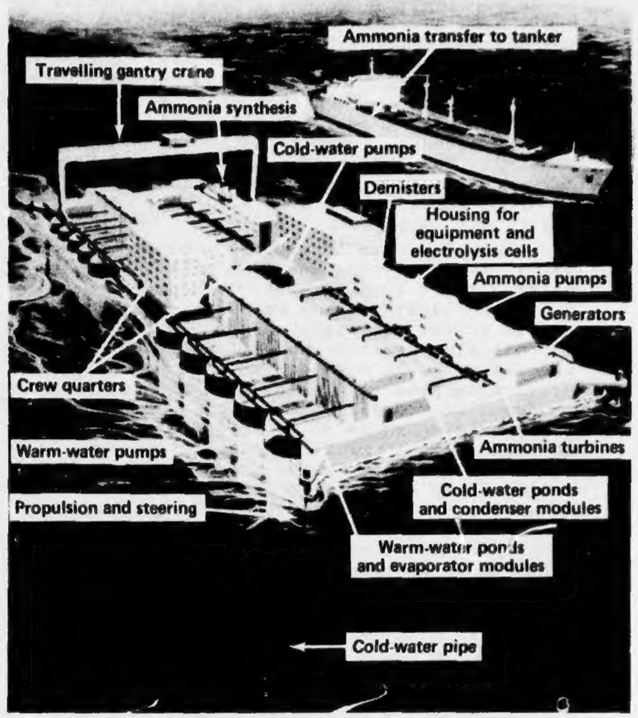

Fig. 1 Concept for 100-MW_e(net), 313-Short-Ton/Day, OTEC/Ammonia Demonstration Plant-Ship for Siting in Tropical Oceans

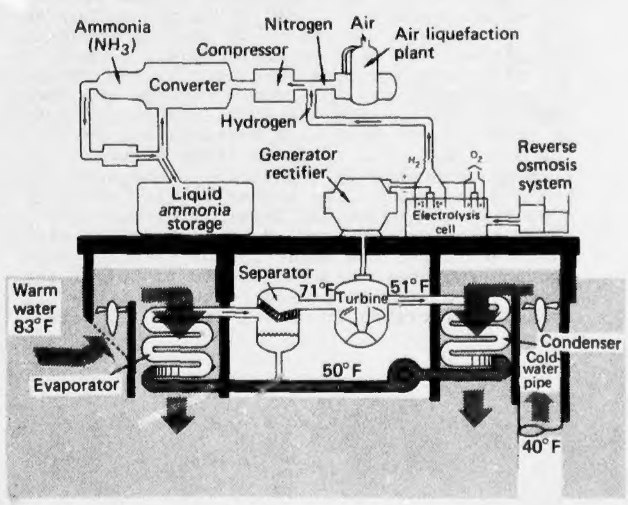

Fig. 2 Simplified Schematic of OTEC Cycle and On-Board Ammonia Production Process

offer the lowest cost and lowest risk option for early OTEC development. Estimated costs for the 100-MW_e ship were extrapolated to a 500-MW_e commercial size that would produce 1697 tons of ammonia per day. For the sixth and subsequent ships the estimated capital cost is $367 million, for which the basic power-plant-ship portion's cost is $566/$kW_e$ (comparable to land-based power plants). The estimated cost for liquid ammonia delivered to U.S. ports is $96/ton compared to reported sales prices near $180/ton. (All costs are in 1975 dollars.)

Ammonia is an attractive product because (a) it is presently made from natural gas, requiring 7% of the increasingly scarce domestic supply by 1985; (b) its manufacture by OTEC requires no raw materials and is a straightforward, nonpolluting process; and (c) OTEC/NH_3 offers promise of being most competitive with NH_3 produced from natural gas and much cheaper than NH_3 produced from coal. Furthermore, ammonia can be decomposed on shore to yield hydrogen for use in fuel cells to produce electricity (Ref. 2). Estimates indicate that electricity from OTEC could become competitive with either coal or nuclear power plants in the 1990's. Other potential benefits include over 200 000 new jobs in shipbuilding, aluminum, cement, new equipment, and U.S. flag shipping by 1986 (Ref. 1). On-board reduction of alumina to aluminum and production of hydrogen also are potentially attractive (Ref. 1).

DISCUSSION

Development of the APL concept for OTEC plant-ships began in 1973. The basic idea was first proposed by d'Arsonval in 1881, and an open-cycle approach was demonstrated by Claude in 1930 (Ref. 3). Modern interest, spurred by the energy crisis and supported by the similarity of the required closed-cycle technology to that of the refrigeration and air-conditioning industries, has been reviewed (e.g., in Ref. 2). The status of projects initiated by the National Science Foundation and transferred to the Energy Research and Development Administration (ERDA) in 1975 was reviewed in a workshop run by APL for ERDA (Ref. 4). That workshop featured studies conducted by industrial teams headed by TRW and Lockheed. The latter studies strongly supported the technical feasibility but indicated that the costs would be high due to study constraints and the selection of titanium heat exchangers, which represented 50 to 58% of the costs. The aforementioned features of the APL concept, described in detail in Ref. 1, were developed with the specific goal of acceptable cost.

Since the APL concept for the heat exchangers is novel, experimental demonstrations being supported by ERDA are required. Initial tests of two-phase-flow heat-transfer coefficients for ammonia inside a 3-in.-diameter electrically heated aluminum tube were begun during the last quarter. Full-scale tests of evaporator and condenser models in a closed loop are planned.

Further investigation of commercialization prospects is also continuing under support of the U.S. Maritime Administration (MarAd). The initial investigation for MarAd (Ref. 1) received substantial contributed support by the Sun Shipbuilding and Dry Dock Company and Avondale Shipyards on ship design. Subcontracted support was obtained from Hydronautics, Inc. on platform motions and other marine aspects; from Woods Hole Oceanographic Institution on site selection and design criteria; from aluminum plant engineering consultants; and from the law firm of LeBoeuf, Lamb, Leiby, and MacRae on international legal considerations. Many companies provided information on the OTEC and product equipment. The potential for successful, near-term commercialization of the vast OTEC resource in tropical oceans appears to warrant substantial early funding and a national priority by government and strong financial support by industry.

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3. G. Claude, "Power from Tropical Seas," Mechanical Engineering, Vol. 52, December 1930, pp. 1039-1044.
4. G. L. Dugger (Ed.), "Proceedings, Third Workshop on Ocean Thermal Energy Conversion, Houston, Texas, May 8-10, 1975," APL/JHU SR 75-2, 1975.

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ENERGY CONSERVATION STUDIES §7
Community Annual Storage Energy System
X9KOCPE/S2P
Support: ERDA-ANL Contract 31-109-38-3627
W. R. Powell
September-October 1976

COMMUNITY ANNUAL STORAGE ENERGY SYSTEM

A project is under way to evaluate the Community Annual Storage Energy System (CASES), a novel heating and cooling system that, according to preliminary studies (Refs. 1 through 3), appears more economical and efficient than methods currently being used. The problem of space heating and cooling with only a small expenditure of energy has a simple technical solution. Surplus heat collected in summer can be stored and used in winter; ice formed in winter can be used for subsequent summer cooling.

The real problem is that it is not economically feasible to obtain all of the energy required for space heating during the winter by simply storing summer heat. For example, suppose during a normal winter a residence requires 10^8 Btu of heat (equal to 1000 gal of oil at a furnace efficiency of 73%). If summer heat is used to heat water to 88°F, and the water is then cooled to 68°F for heating during the winter, 5 000 000 lb of water must be stored. The storage volume required, 8×10^4 ft^3 (a cube 43 ft on an edge), is larger than the residence. However, if a heat pump is used to remove additional heat from the water until it is frozen, then each pound of water provides ten times more heat. Each pound of water can be used many times during the winter as it is often warm enough, especially in the southern U.S., to melt ice with heat that is available naturally.

The cost of the ice-making heat pumps and ice-water storage tanks is greatly reduced if an entire community shares a common centrally located facility. The cost of such a facility and the required distribution system appears to be significantly less than the aggregate cost of conventional heat pumps when the capital invested by the electric utility to service air-conditioning loads is included. In CASES, when heat pumps are run to provide heat, the resultant cooling is saved as ice, so that little electric power is required during the summer for cooling. Thus the electric bill is only half as large as when a conventional heat pump runs during summer and winter. The operating cost of cooling by a system such as CASES can also be reduced in most locations that require net seasonal cooling by collecting part of the required ice in winter from nature. Also, for a location requiring net seasonal heat, the larger buildings of the community typically generate surplus heat, even in winter, resulting from lights, people, and equipment. This heat can be supplied to smaller buildings via a heat pump with a further reduction in heating costs.

Another attractive feature of the CASES approach is that life-cycle-cost arguments need not be advanced to justify cost and energy savings. Initial building costs are less since the building owner subscribes to a thermal utility and does not need to purchase or install heating or cooling machinery. Thus CASES appears to save capital, reduce building costs, and conserve at least half of the energy currently used for space conditioning.

DISCUSSION

Natural cooling is often available at temperatures low enough to cool buildings directly by means of affordable cooling coils and storage facilities. In general the cooling coils located in buildings with a CASES setup will be sized so that normal cooling loads can be met with 45°F coil water. Water at that temperature or lower can be obtained from the ice-water storage pond as long as ice is present. When the store of ice is exhausted, the heat pumps can be run at night to store cooling capacity at off-peak rates. Even if ice is formed naturally, it will not be economical to provide a storage facility large enough to avoid some artificial cooling at the end of an unusually long hot summer. During the first part of the summer, when the ice plant is not needed, it can run for its normal purpose, i.e., the manufacture and sale of ice. Thus the equipment in CASES can be fully utilized even if it consumes electric power for space conditioning in buildings only part of the year.

The distribution system required for CASES is most economical and reliable if it does not require insulated pipe. Consequently, the cold-water line operates in the 40 to 45°F temperature range and the warm-water line at 60 to 70°F. To produce heat for a building or a cluster of residences, water is drawn from the warm-water line, passed over the evaporation coil of a heat pump (traditionally referred to as a "chiller"), and returned to the cold-water line at 45°F. This temperature is the upper limit of the cold-water line, although chiller return water may be a degree colder in large systems to compensate for ground heating. For cooling, water is drawn from the cold-water line and passed directly through the building cooling coils at a flow rate that returns it to the warm-water line at the lower temperature limit, approximately 60°F. In general, the temperature difference between the two main lines of the distribution system is about 20°F; neither temperature differs significantly from that of the ground. These temperatures are not yet firmly chosen and can vary with the season and local conditions.

In traditional use, chillers usually waste more heat by rejection at the cooling tower than is required for the entire year by the building they serve. In CASES, chillers are run only for heat; any surplus cold produced is sent to the ice plant via the cold-water line for storage. The heat produced at the ice plant in the process of converting part of this cold water into ice is returned to the community via the warm-water line. Because CASES uses both the warm and cold outputs of its heat pumps rather than wasting the out-of-season output, it would be more fuel efficient than conventional heat-pump systems even if it did not also take advantage of natural heat and cold.

Part of the diurnal peak flow taken from the warm-water line (heat input to the chiller heat pumps) would come from short-term warm-water storage reservoirs, thus ensuring steady operation of the ice plant. Likewise, part of the cold water returned to the ice plant would be stored in short-term cold-water reservoirs.

When free heat is available from the air during the season when heating loads dominate the average short-term requirements, water from the cold-water reservoir can pass through a heat exchanger and be heated. Heat collected from the air can be added to the warm-water store. Also, in southern sites, the heat accumulated as warm water from the cooling of buildings can be dumped into the outside air on cold nights. Cooled by nature on cold nights, this water can then be added to the cold-water store.

The thermal balance point for a detached home is typically about 65°F; however, for a well-insulated office building, it may be only 10°F. Consequently, at selected times during the year water may be taken from the cold-water lines to cool commercial buildings at exactly the same rate as it is returned to the cold-water lines from the heat pumps used to heat smaller buildings. The central facility only makes up for the imbalance in the heating and cooling needs of the community. In the CASES concept, part of this imbalance is also supplied from previously stored energy that was obtained from nature. In southern locations, natural cooling is used in winter to form ice whenever possible; in northern sites, heat is collected during every warm spell. By proper choice of the community mix and by proper use of natural cold and available heat, a seasonal balance for the community can be achieved in much of the United States. Dramatic fuel savings result from balancing the community's heating and cooling needs both annually and diurnally with low-cost natural cold and available heat via thermal storage facilities.

Fundamentally, it is the avoidance of conventional thermal waste and the greater cooperation with nature that permit CASES to operate with significantly lower seasonal energy consumption.

FUTURE PLANS

In order to evaluate the seasonal performance of the CASES concept, an interactive model will be constructed. Various design changes and operational strategies will be tested with at least a full year of weather data. Systems control and the effect of equipment or sensor failure must also be studied. The only technical problems in the CASES concept are system problems since all of the equipment required has been in commercial service for many years.

REFERENCES

1. "Technical Program Plan for the Development of CASES," APL/JHU AD-6700-104, May 1976.
2. "CASES Report 1, Contract ANL 31-109-38-3627," October 1976.
3. "CASES Report 2, Contract ANL 31-109-38-3627," November 1976.

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